Challenging the Accepted Views of Financial Pattern Recognition at Different Frequencies

Introducing the High Frequency Trading Ecosystem (HFTE) & the UnforTunate cOst of Pattern rEcognition (UTOPE-ia)

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Connection to other fields

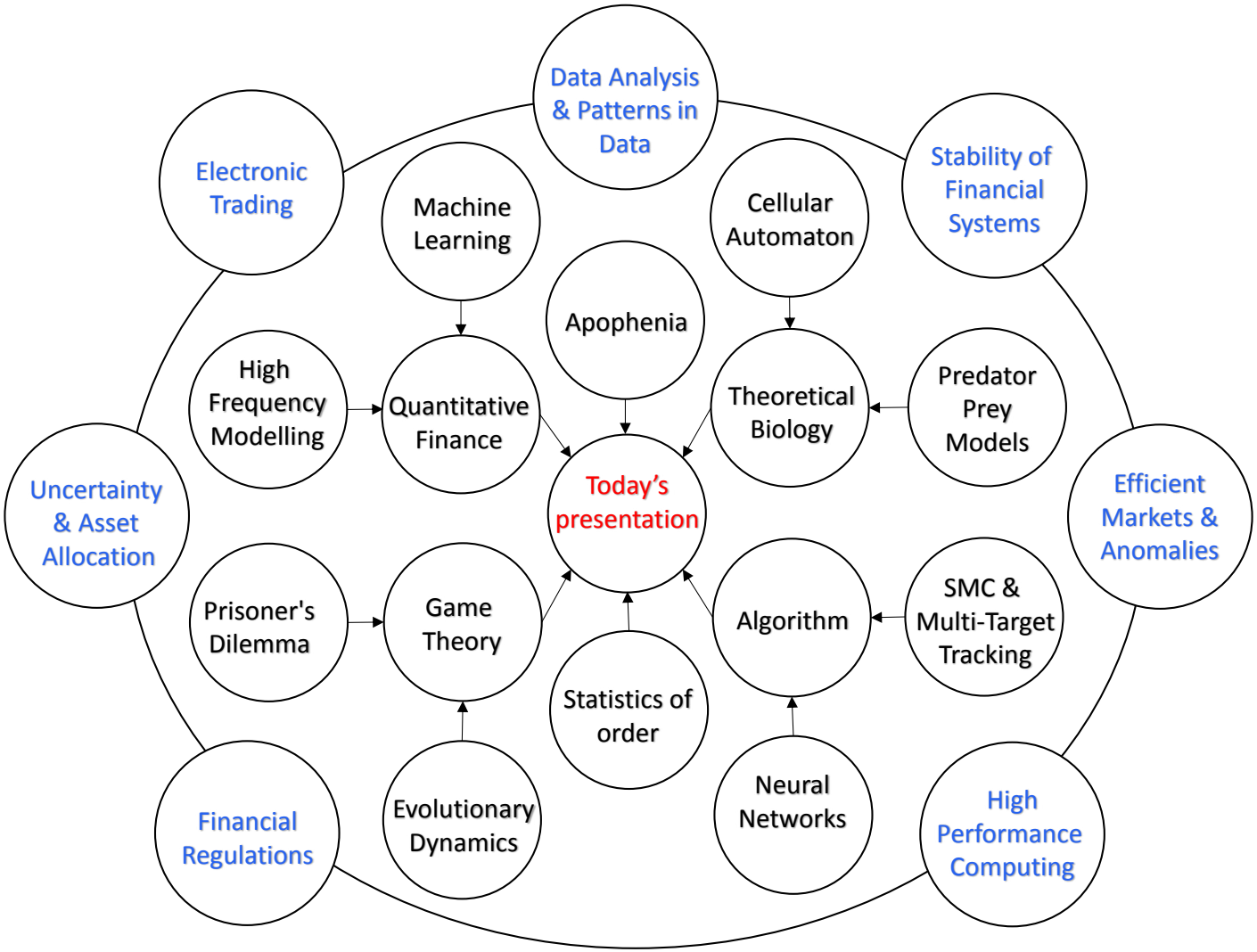
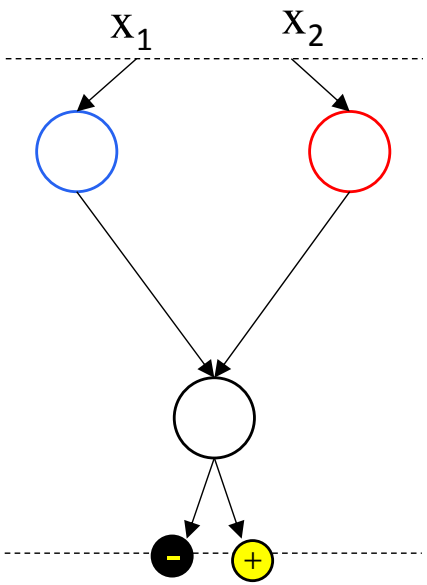


Figure: Academic schemes & fields involved in the HFTE and the UTOPE models

Connecting Simple Neural Network with linear regressions

Network Structure for LR



LR function representation

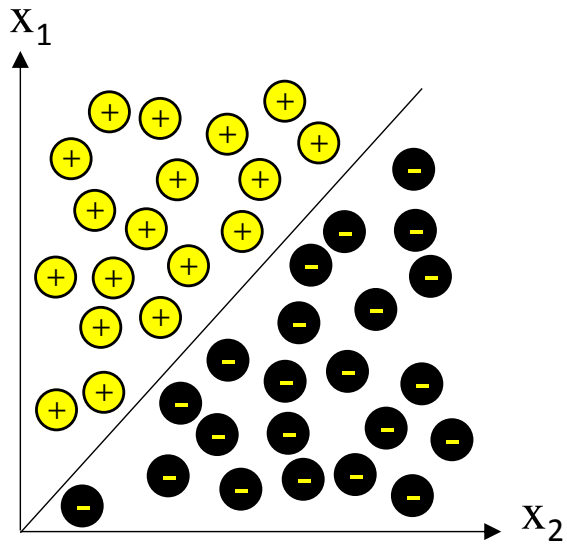
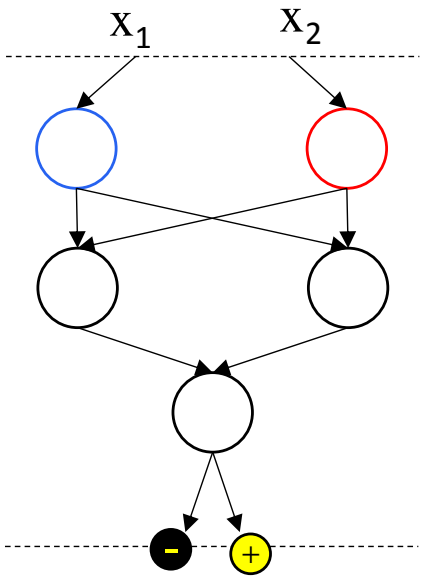


Figure: Simple Neural Network modeling a linear regression

The hidden layer, the answer to the XOR function

Network Structure for XOR



XOR function representation

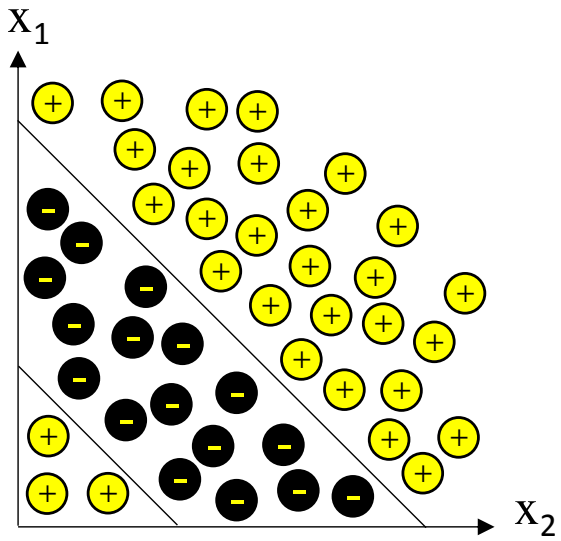
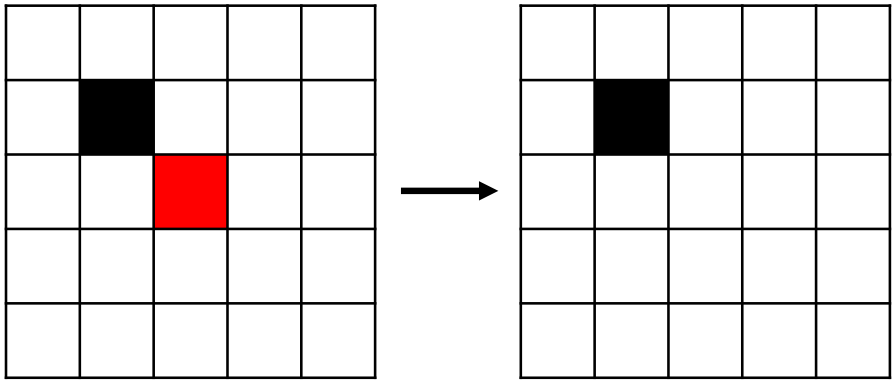


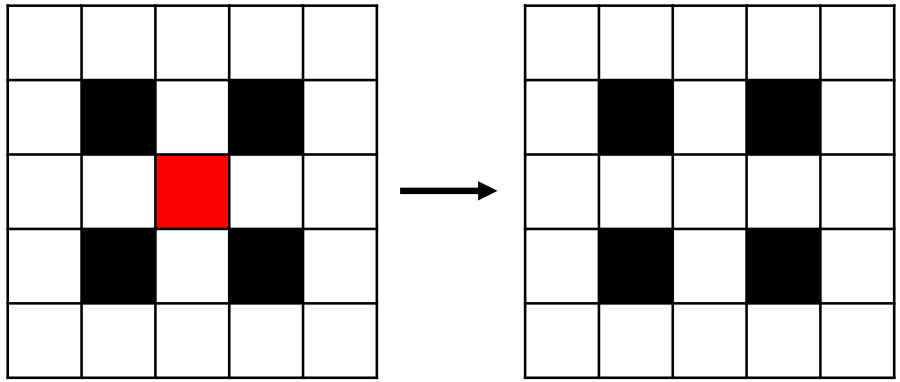
Figure: Feedfoward ANN with 1 hidden layer & the XOR function

Cellular Automatons: Conway's Game of Life

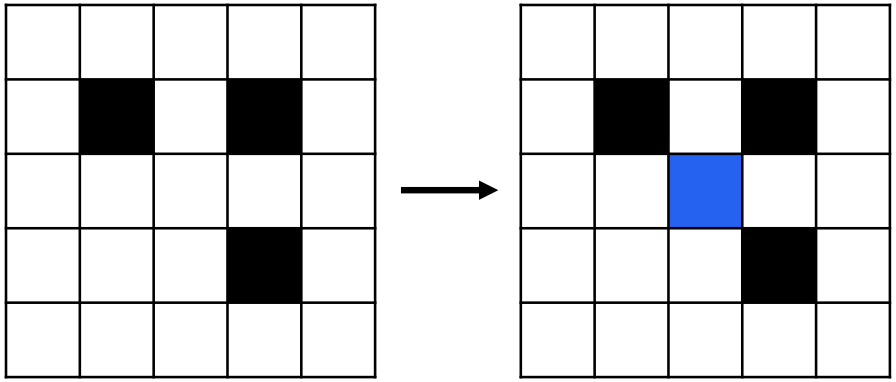
a) Death "by loneliness"



b) Death "by overpopulation"



c) Reproduction



d) No change "otherwise"

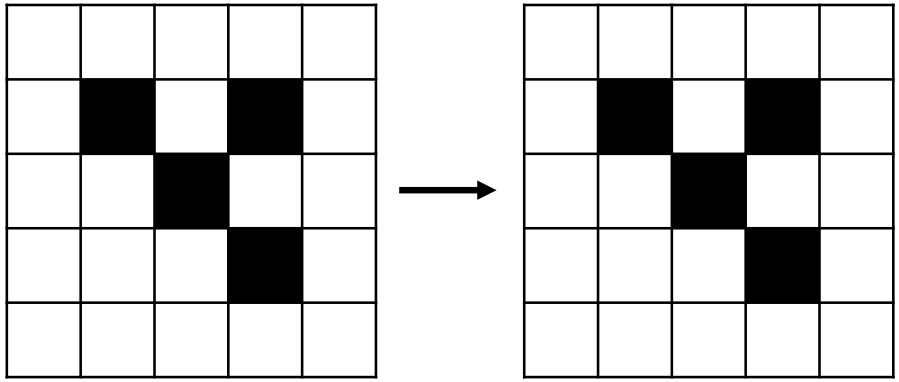


Figure: Conway's Game of Life rules illustrated

Game of Life (complexity arises from simple rules)

Conway's Game of Life assumes that **complexity** in an ecosystem **arises from simple rules**. For instance these rules can lead to a family of different types of automatons. As reminder you may get:

- **Stable forms** ("Block", "Beehive", "Loaf", "Boat").
- **Oscillating forms**: ("Blinker (2 period)", "Toad (2 period)", "Pulsar (3 period)", the "Pentadecathlon (15 period)".

Intuitively the reader may guess that the concept of **financial stability** (systemic risk) or **financial cycles** or HF oscillations like of figure 9 may be induced through a similar scientific methodology.

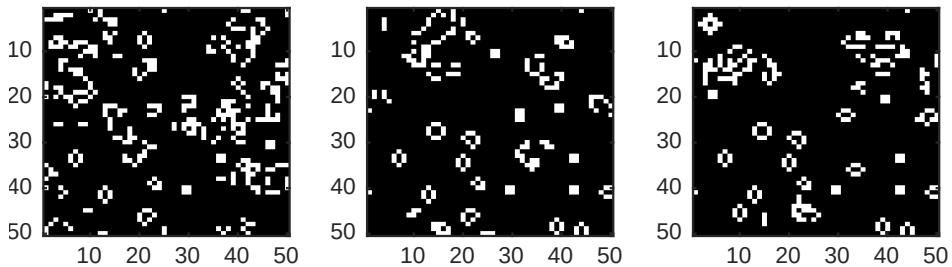


Figure: 3 snapshots of a simulation of Conway's Game of Life.

1. Introduction
   - Algorithms not usually associated with finance
   - Theoretical biology material not usually associated with finance
   - Statistics not usually associated with finance
2. Challenging the views of pattern recognition at low frequency
   - What is the Unfortunate cosT Of Pattern rEcognition?
   - Other well know related concepts to UTOPE
   - UTOPE as a virus to the financial systems
3. Challenging the views of pattern recognition at high frequency
   - Observations & Background
   - Quantitative Strategies & the High Frequency Financial Funnel
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Lotka Volterra 3-species

The intuition behind the Lotka Volterra 3-species **ecosystem** can be illustrated by an example: we have **Sharks** (z), **Tunas** (y) and **Small Fishes** (x), with tunas eating small fishes which in turn are eaten by sharks which die of natural causes. Equation (1) formalize this interaction

$$\begin{cases} \frac{dx}{dt} &= ax - bxy \\ \frac{dy}{dt} &= -cy + dxy - eyz \\ \frac{dz}{dt} &= -fz + gyz \end{cases} \tag{1}$$

More specifically If all **eigenvalues** of $J(x, y, z)$ have **negative real parts** then our system is **asymptotically stable**.

$$J(x, y, z) = \begin{bmatrix} a - by & -xb & 0 \\ yd & -c + dx - ez & -ye \\ 0 & -zg & -f + gy \end{bmatrix} \tag{2}$$

Lotka Volterra 3-species

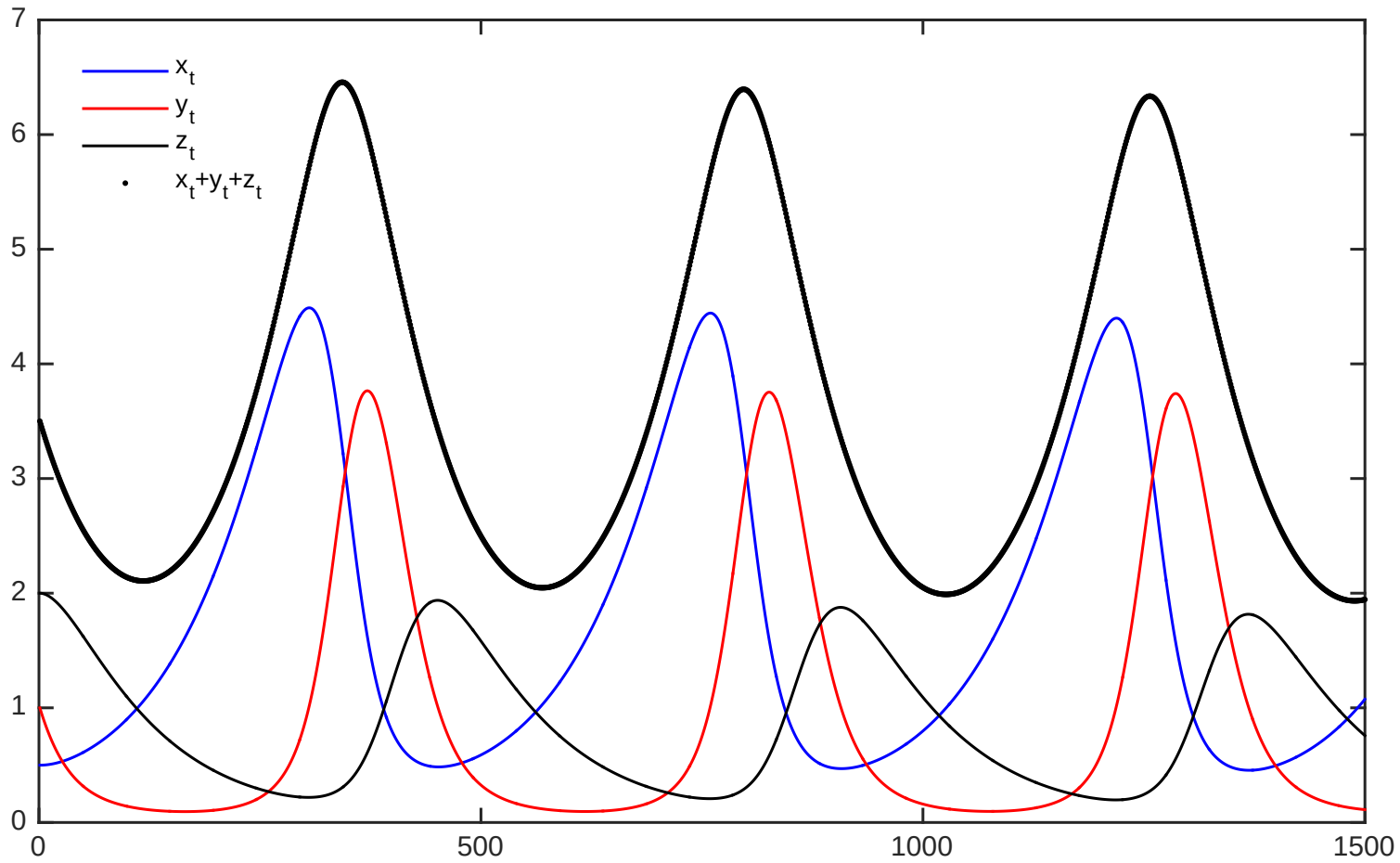

Figure: The Lotka Volterra 3-species food chain equation 1 with $x_1 = 0.5$, $y_1 = 1$, $z_1 = 2$ and $a = b = c = d = e = f = g = 1\%$

Evolutionary Game Theory

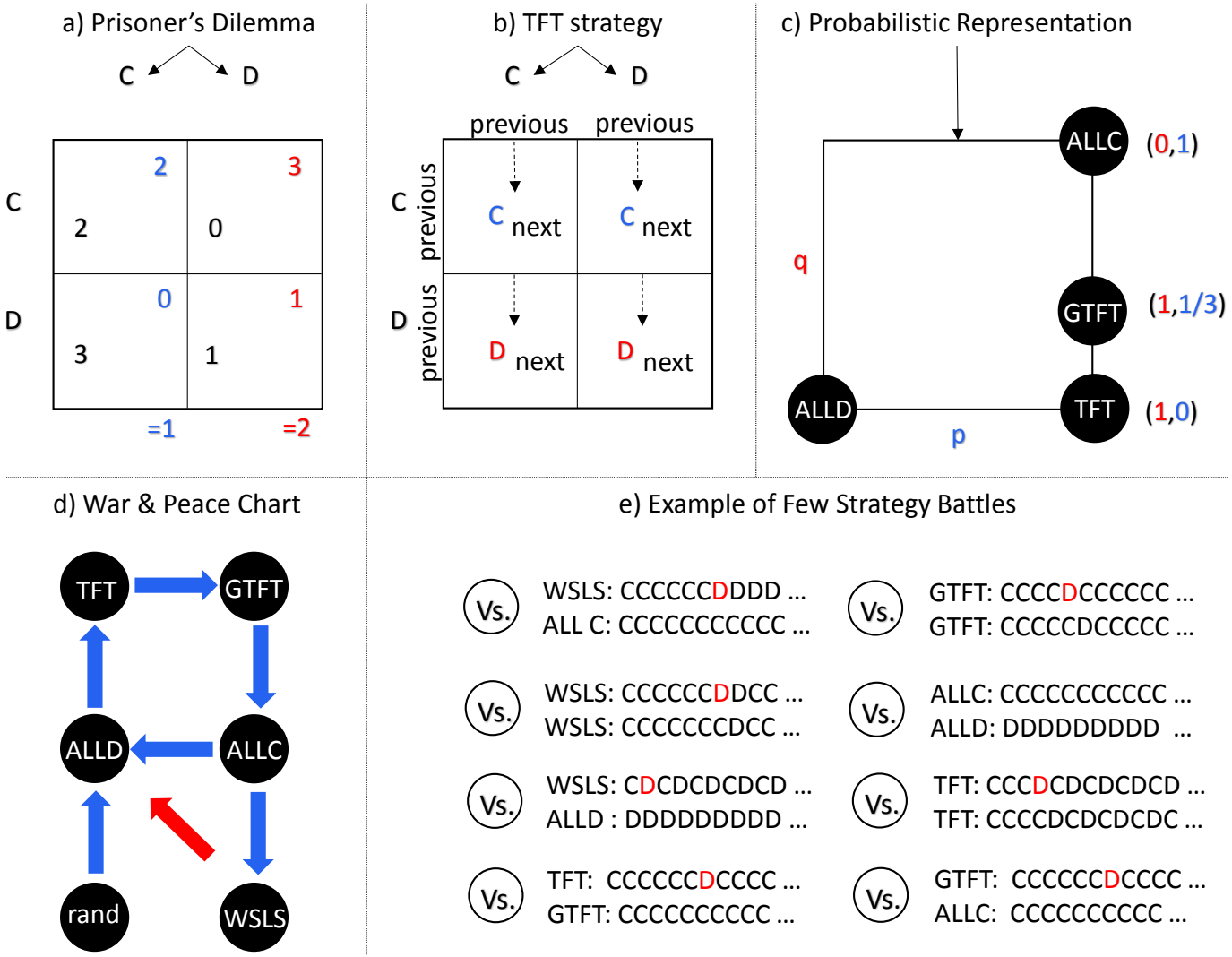

Figure: Some classic Game theory representations

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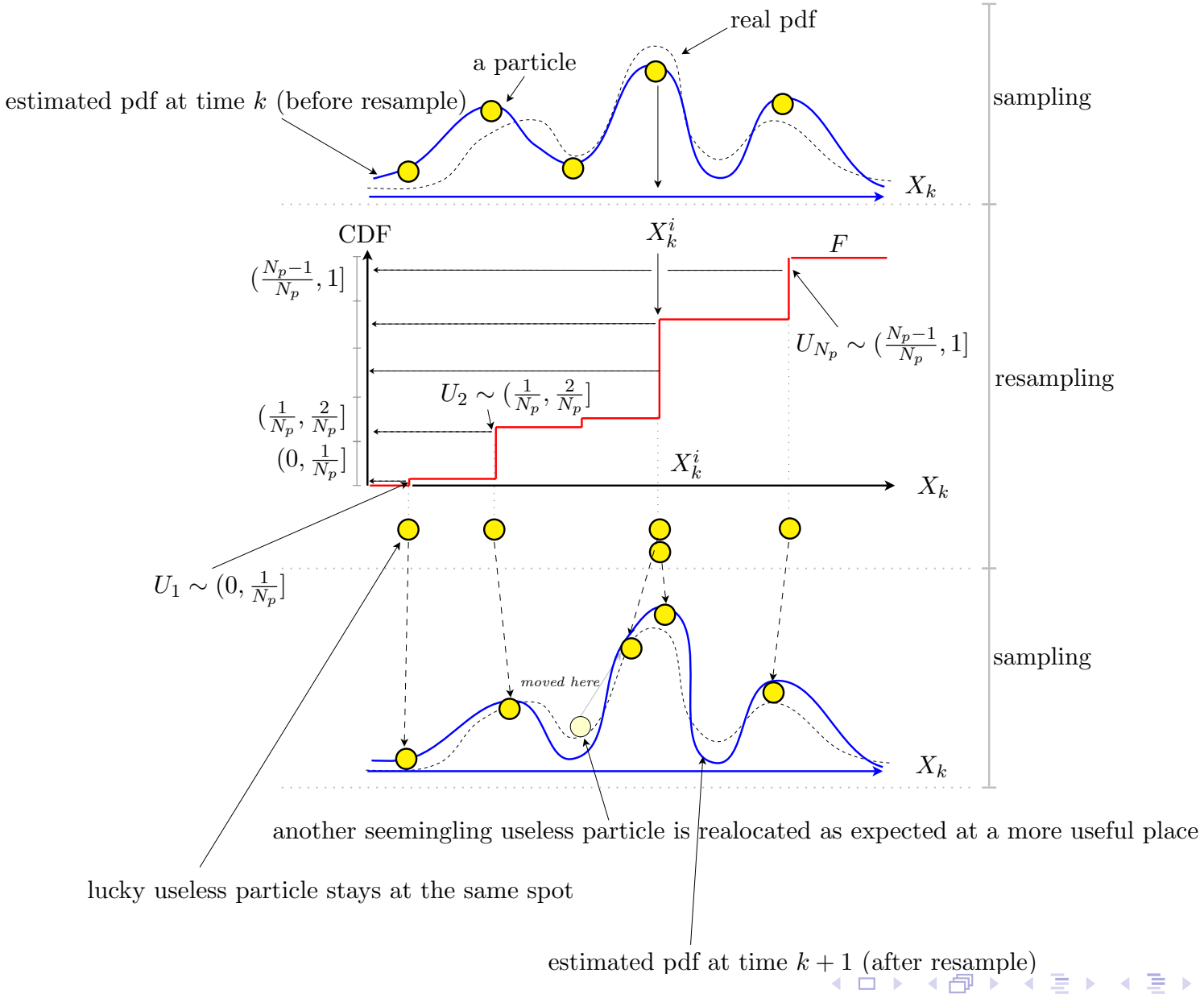
Sequential Monte Carlo Method



Statistics of order

Theorem

Let's call X be an iid random variable with density f and CDF F, then the k-th statistics of order is given by equation (3).

$$f_{X_{(k)}}(x) = \frac{n!}{(k-1)!(n-k)!} F(x)^{k-1}(1-F(x))^{n-k} f(x). \tag{3}$$

Example

if $X_i \sim [0,1]$, $i \in \{1, \dots n\}$, $X_{(1)} = \min\{X_1, \dots, X_n\}$,
$X_{(n)} = \max\{X_1, \dots, X_n\}$ then $\mathbb{E}[X_{(1)}] = \frac{1}{n+1}$, $\mathbb{E}[X_{(n)}] = \frac{n}{n+1}$.

Example

You work in a hedge fund, you are assigned the task to find a working strategy. You try 10 strategies and have created a performance factor going from 0 to 1. How do you proceed?

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What is the Unfortunate cosT Of Pattern rEcognition?

- **Definition**: the **asymmetry** in the cost-benefit ratio of pattern recognition explains what we define as the **u**nfortunate cos**t** **o**f **p**attern r**e**cognition that we will call **UTOPE** for short. To emphasis the **huge benefits** of seeing a true pattern **quickly** compared to the **small cost** of being mistaken with respect to a false pattern has created an evolutionary incentive for our brains to see patterns sometimes when there are none.
- **Biological** background: **evolution** is the survival of the fittest. Those less well adapted (not as good at finding food and those who are not able to deal with predators) will not survive to reproduce, and so will be deleted from the gene pool. For **example** if you **associate a noise to a predator**, then if you **hear something** similar, you won't take the risk of staying around and will willingly use energy (cost) to escape. The **benefit** (**saving ones life**) of escaping if that was a real predator (true pattern) far outweighs the **cost** (**energy used to move quickly**) of being mistaken of it was a false alarm (false pattern).

Other well know related concepts to UTOPE

- **Apophenia** is the technical name for some of the consequences of UTOPE,(seeing meaningful patterns when they do not exist). This might be best illustrated with a fairly bizarre phenomenon, **pareidolia**: seeing faces or words in toast/clouds and other objects or physical shapes that can exhibit a degree of randomness.
- **Superstition**: happens a great deal in sports, **Michael Jordan** (NC short), **Björn Borg** (beard in Wimbledon).
- **Design**: everything that mimics design must have a designer, this is the reason why Darwin's theory of evolution was so difficult to grasp when it first came since it explained the incredible diversity
  Inferring a creator from an object is often well justified. For example, when we see a table, although we may not know the specific carpenter, we assume that there was, nevertheless, some carpenter. In fact, so often are our inferences verified that we sometimes find it difficult to believe that there is no creator when some- thing seems to have been created.

Other well know related concepts to UTOPE

- **Skinners experiment**: Famous experiment which examined the formation of superstition in pigeons. Skinner placed a number of **hungry pigeons** in a number of cages attached to an automatic mechanism that **delivered food** at regular intervals with no reference whatsoever to the birds behavior. He discovered that the pigeons **associated** the delivery of the **food** with whatever chance **actions** they had been performing. They subsequently continued to perform these same actions (eg: turning anti-clockwise/clockwise, looked over their shoulders, others developed a pendulum motion, etc...).
- **Alternative therapies**: such as **homeopathy** and faith healing, have repeatedly been shown to be ineffective yet important markets exist.
- **Gambling**: everyone knows about casinos **business model**, yet many people still play because of mixture associated to lack of understanding of statistics of order/**survival bias** (eg: horse racing) and reinforcement.

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UTOPE as a virus to the financial systems

- **Trading Strategies' performances**: Strategies are ranked from low to **high performing** and only the ones with a significantly **high sharpe** ratio's are published creating a **survival bias**. Ranked from lowest to highest can be easily misleading if the statistics of order is not taken into consideration.
- **Trader's compensation**: There is no time to investigate **a great trader** to a **lucky trader** and shortcuts are taken as a result.
- **Sales and structured products**: Many offered strategies are **optimized** in sample **random** walks **reinforced** with **stories**.
- **Hedge Fund recruiting**: Investors trust these **well-known academic names** to be competent to manage their money.
- **Technical Analysis**: Non verifiable pseudo scientific trading strategies are presented as "Art" (which usually has a positive connotation in people's mind) as opposed to a verifiable scientific methodology.

UTOPE virus: financial systems aggravating factors

- **Peer pressure and authority figures** have a significant effect on the way we act and the beliefs we form. Asch conducted an experiment which showed what many already believed to be true, namely, that if **there are enough people who disagree** with what someone has said, then **that person can be convinced to change their mind** with nothing more than a suggestion that others opinions differ.
- **Asymmetry in personal to client risk**: Hedge fund managers usually speculate on their client money and, given the year bonus system, the strategy become increasingly risky, **short term** or asymmetry in the time-line in the **draw-down** of the strategy (eg: FX carry) since they face very little risk themselves.
- **Underpaid regulators**: the salary hierarchy is such that the **best mathematical talents** go on working for **hedge funds and banks** because the salaries are higher. The rest go to **low paid but critically important positions** for the stability of the financial markets (regulators, CCPs).

An observation from the market

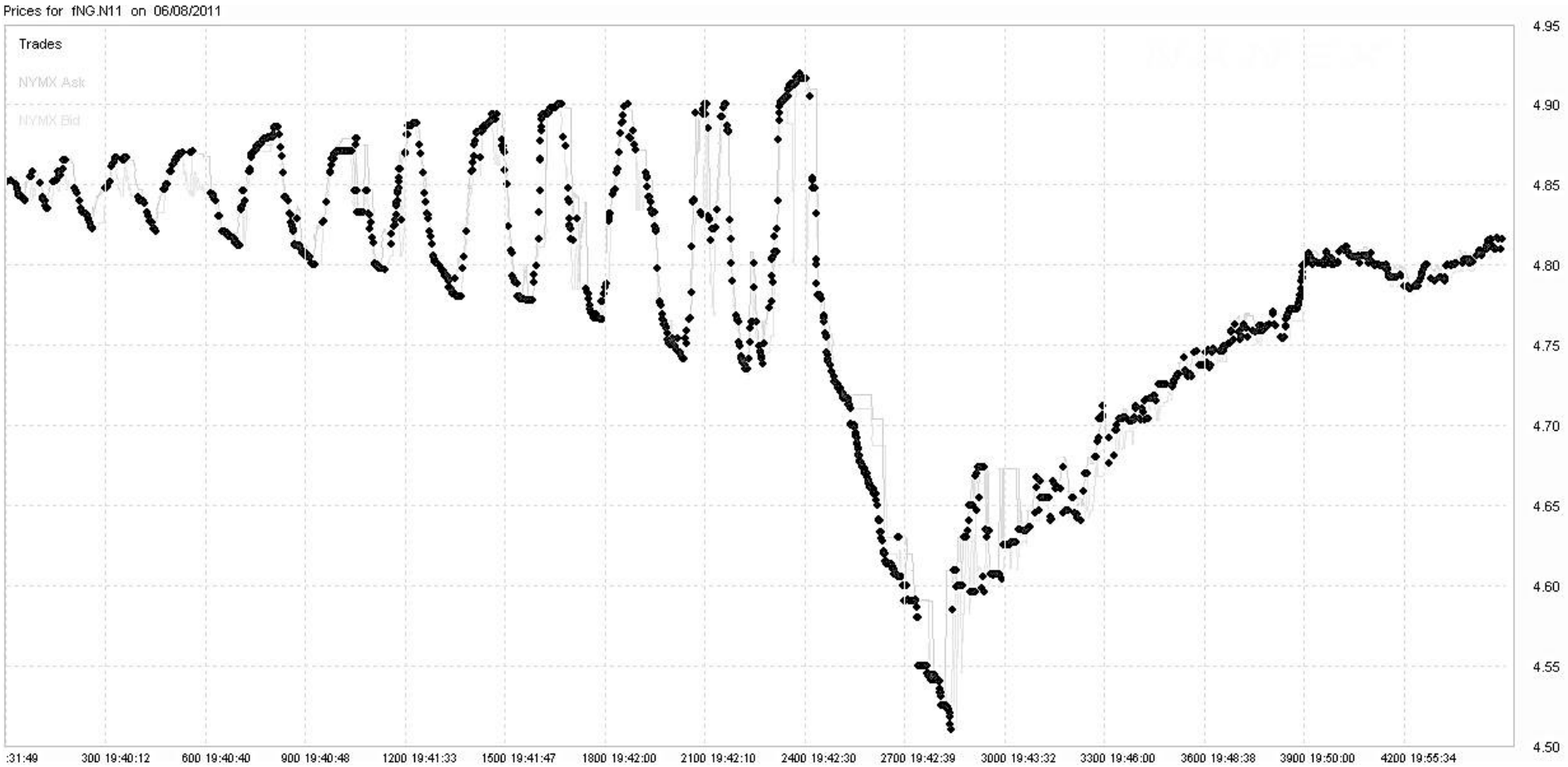

Figure: Natural Gas flash crash of 06/08/2011 (nanex)

Background: Order-books

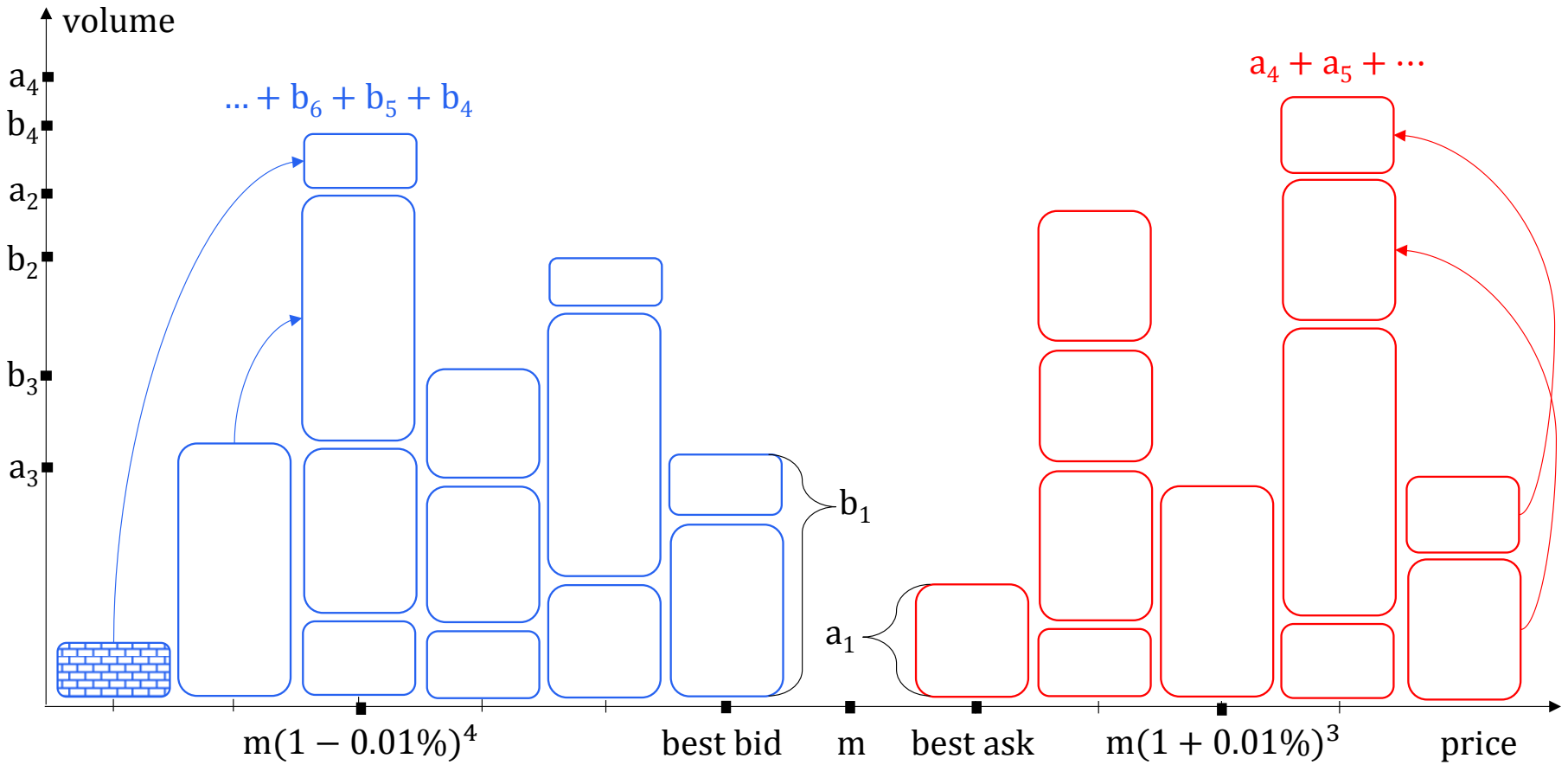

Figure: Order-book visual representation

High Frequency Financial Funnel

We assert that Martin Nowak's Funnel is the simplest possible network to model (therefore which minimizes overfitting) the key functions for our application. The area of evolutionary graph theory is quite rich. Many graphs provide interesting properties. We can formalize the learning process from all of our strategies using the topology of figure 11 by providing a set $\mathcal{T}$, as described by equation (4) of weights corresponding to all the possible weights of this particular figure.

$$\mathcal{T} \triangleq \left\{ \begin{array}{cc} \cup_{j\in[1,9]} w^{i}_{\bar{s},j} & \cup_{j\in[1,9]} w^{i}_{s,j}, \\ \cup_{j\in[1,9],i\in[1,3]} w^{h_1}_{\bar{s},i,j} & \cup_{j\in[1,9],i\in[1,3]} w^{h_1}_{s,i,j}, \\ \cup_{j\in[1,3]} w^{h_2}_{\bar{s},j} & \cup_{j\in[1,3]} w^{h_2}_{s,j}, \\ w^{o}_{\bar{s},j\in[1,9]} & w^{o}_{s,j\in[1,9]} \end{array} \right\} \tag{4}$$

with w^i, w^h and w^o, respectively the weights associated to the input, hidden and output layers.

High Frequency Financial Funnel (HFFF)

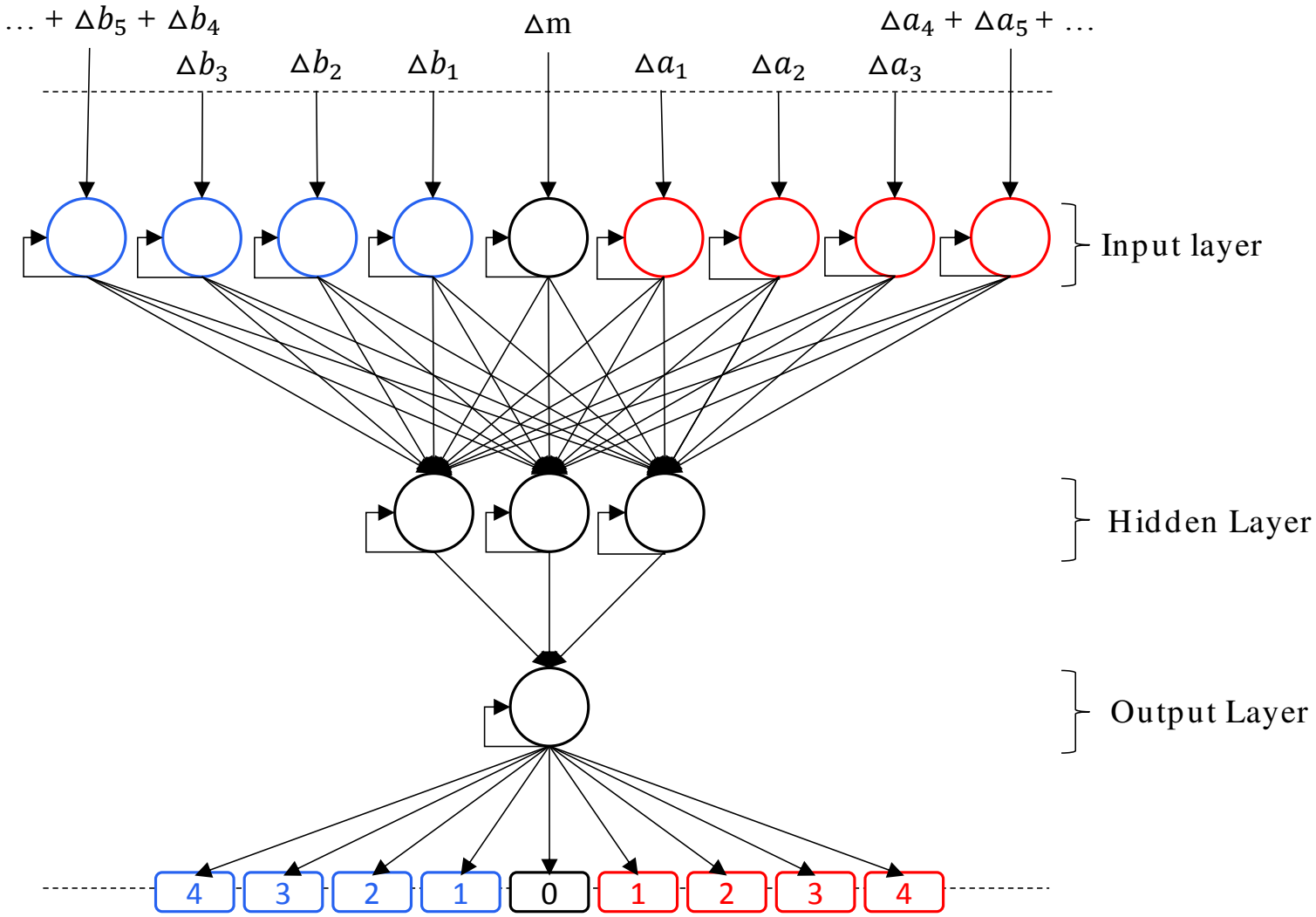

Figure: The High Frequency Financial Funnel

Trend Following (TF)

The idea of the TF is that if the price has been going a certain way in the recent past, then it is more likely to follow the same trend in the immediate future. The mathematical formulation of a TF can be diverse but in the context of this paper we will be using an exponentially weighted moving average (EWMA) formally described by equation (5).

$$\hat{x}_t = (1-\lambda)x_t + \lambda\hat{x}_{t-1},\ \lambda \in [0,1] \tag{5}$$

In equation (5), λ represents the smoothness parameter. The lower the λ, the more the next move will be conditional to the immediately adjacent previous move. The HFFF can model trend following strategies.

Proof.

Simply set $\cup_{j\in[1,4]} w^i_{\bar{s},j} = 0$, $\cup_{j\in[1,4]} w^i_{s,j} = 0$, $\cup_{j\in[6,9]} w^i_{\bar{s},j} = 0$, $\cup_{j\in[6,9]} w^i_{s,j} = 0$ $\cup_{j\in[1,4],i\in[1,3]} w^{h_1}_{\bar{s},i,j} = 0$, $\cup_{j\in[1,4],i\in[1,3]} w^{h_1}_{s,i,j}$ $\cup_{j\in[6,9],i\in[1,3]} w^{h_1}_{\bar{s},i,j} = 0$, $\cup_{j\in[6,9],i\in[1,3]} w^{h_1}_{s,i,j}$, $w^h_{\bar{s},3} = 0$, $w^h_{s,1} = 0$ and $w^h_{s,3} = 0$. □

Trend Following in HFFF representation

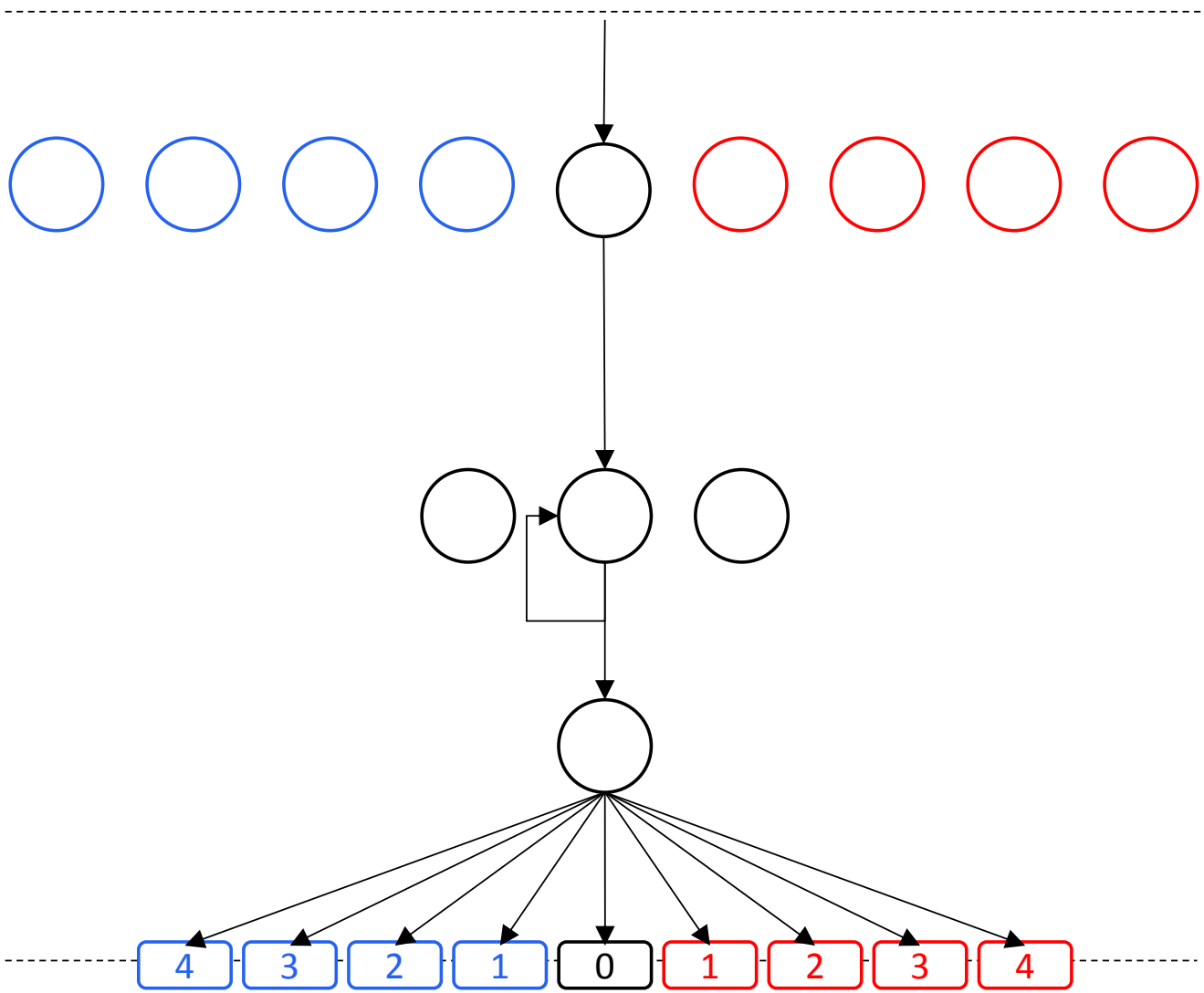

Figure: The EWMA strategy translated in terms of network topology

Differences of Trends in HFFF representation

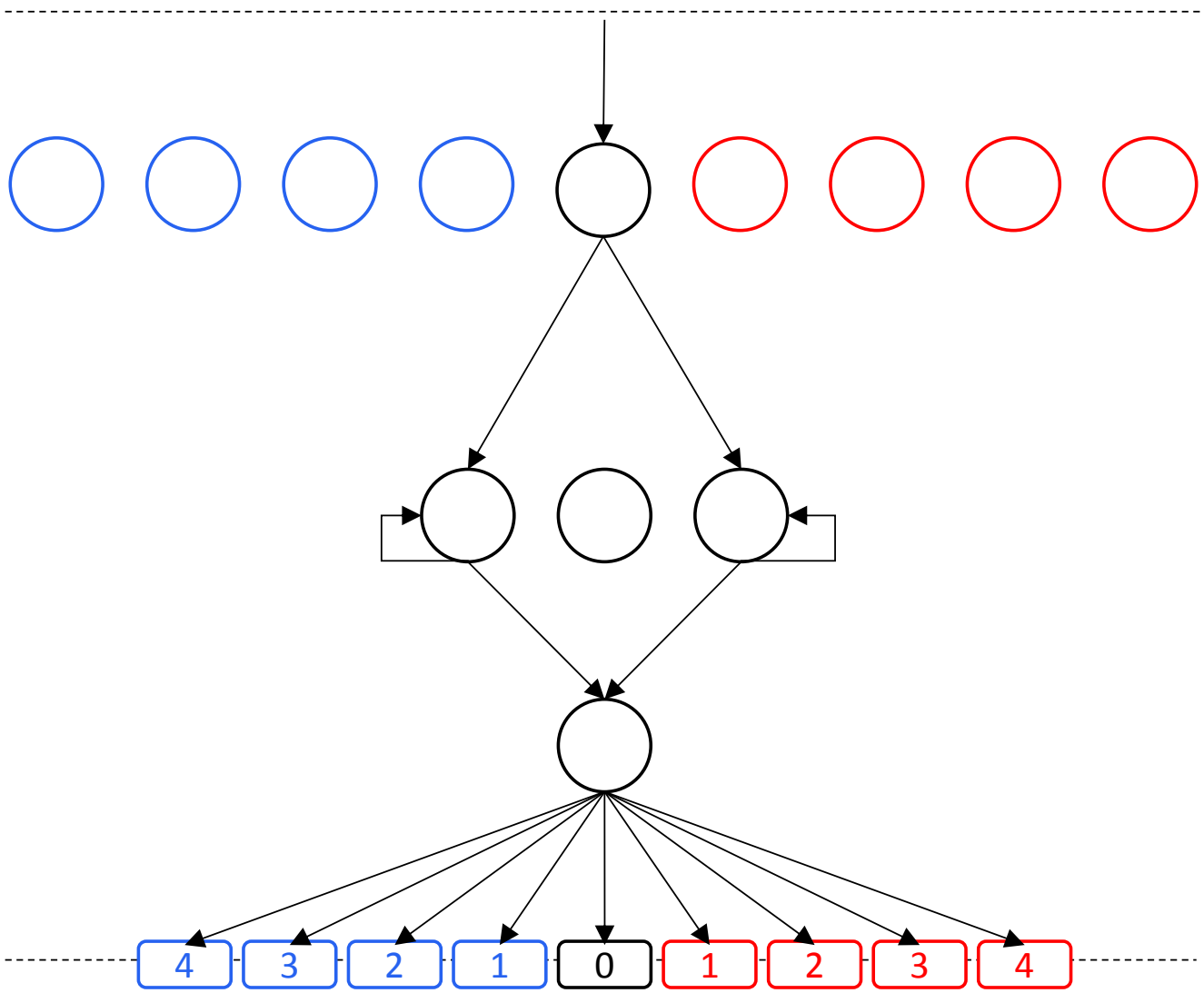

Figure: Difference of 2 EWMAs strategies translated in terms of network topology

Regressions (Linear, Logistic)

The Multi Linear Regression (MLR) is another well known 101 type strategy traders have been using in the industry. Given a data set $\{y_i, x_{i-1,1}, \ldots, x_{i-1,9}\}_{i=1}^{n}$ where n is the sample size, and y_i then our MLR is formalized by the equation below :

$$\begin{aligned} y_i &= \beta_1 x_{i-1,1} + \cdots + \beta_9 x_{i-1,9} + \varepsilon_i \\ &= \mathbf{x}_{i-1}^{\mathrm{T}} \beta + \varepsilon_i, \ \ i = 1, \ldots, n \end{aligned}$$

where T denotes the transpose, so that $\mathbf{x}_{i-1}^{\mathrm{T}} \beta$ is the inner product between vectors x_i and β. The HFFF can model multi linear regression like strategies.

Proof.

Simply set $\cup_{j\in[1,4]} w_{\bar{s},j}^{i} = 0$, $\cup_{j\in[1,4]} w_{s,j}^{i} = 0$, $\cup_{j\in[6,9]} w_{\bar{s},j}^{i} = 0$, $\cup_{j\in[6,9]} w_{s,j}^{i} = 0$, $w_{\bar{s},1}^{h} = 0$, $w_{\bar{s},3}^{h} = 0$, $w_{s,1}^{h} = 0$, $w_{s,3}^{h} = 0$. □

Regressions (Linear, Logistic)

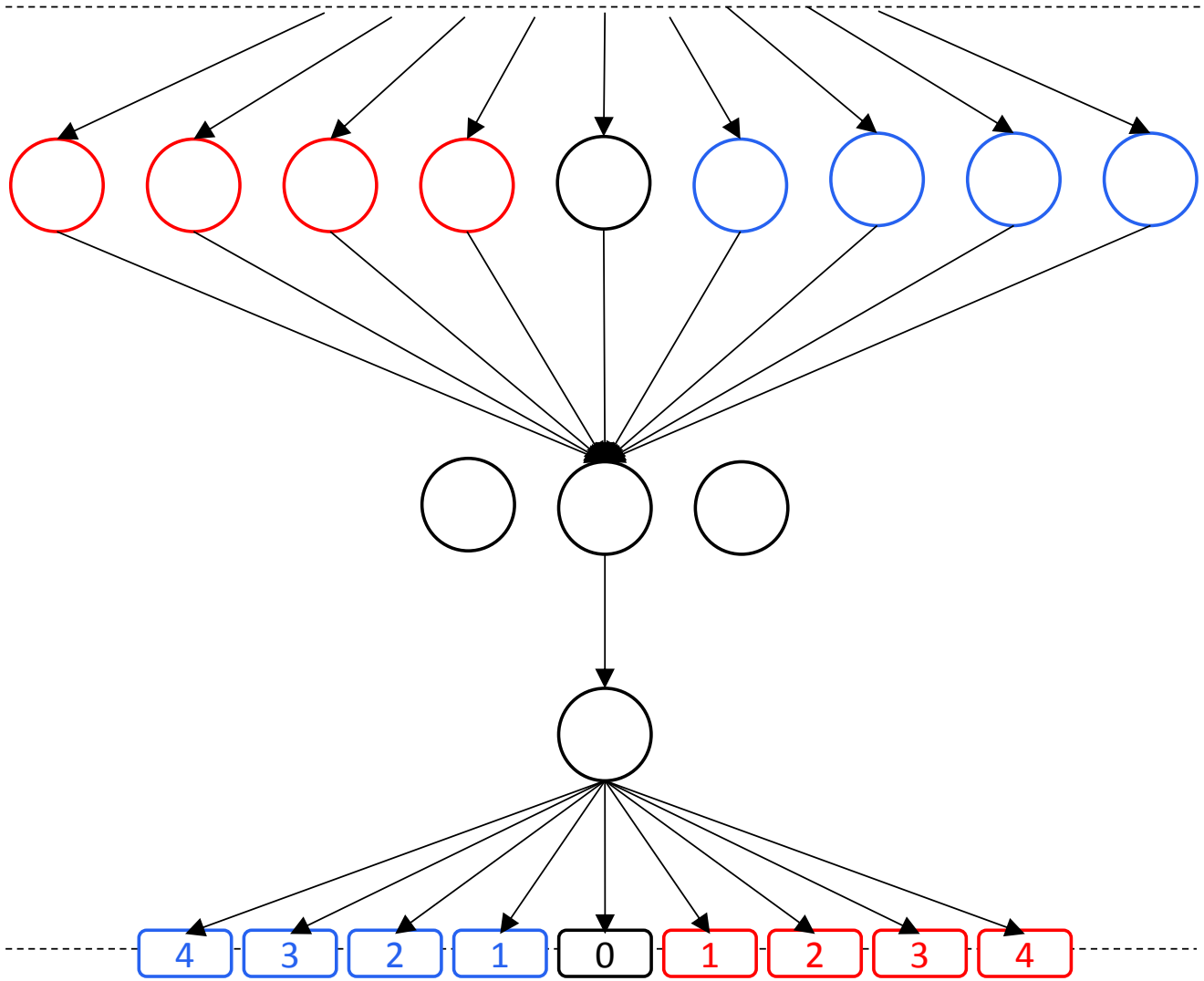

Figure: The MLR strategy translated in terms of network topology

XOR rational

I_1	I_2	O
1	1	0
1	0	1
0	1	1
0	0	0

Table: The truth table of the XOR function

Let's look at the following known HF rational. If we define the Open Interest (OI) as being the total volume left on the order book then it is known that when:

- price and the OI are rising then the market is bullish,
- Price is rising but the OI Falling then the market is bearish,
- Price is falling but the OI rising then the market is bearish,
- Price is falling and the OI falling then the market is bullish.

XOR strategy

These 4 market situations can be summarized by table 27.

Price	Open Interest	Signal
Rising	Rising	Buy
Rising	Falling	Sell
Falling	Rising	Sell
Falling	Falling	Buy

Table: The Relationship Between Open Interest, Price & Signal

The HFFF can model XOR like strategies.

Proof.

Simply set $\cup_{j\in[1,4]} w^i_{\bar{s},j} = 0$, $\cup_{j\in[1,4]} w^i_{s,j} = 0$, $\cup_{j\in[6,9]} w^i_{\bar{s},j} = 0$, $\cup_{j\in[6,9]} w^i_{s,j} = 0$, $w^h_{\bar{s},1} = 0$, $w^h_{\bar{s},3} = 0$, $w^h_{s,1} = 0$, $w^h_{s,3} = 0$. □

XOR strategy

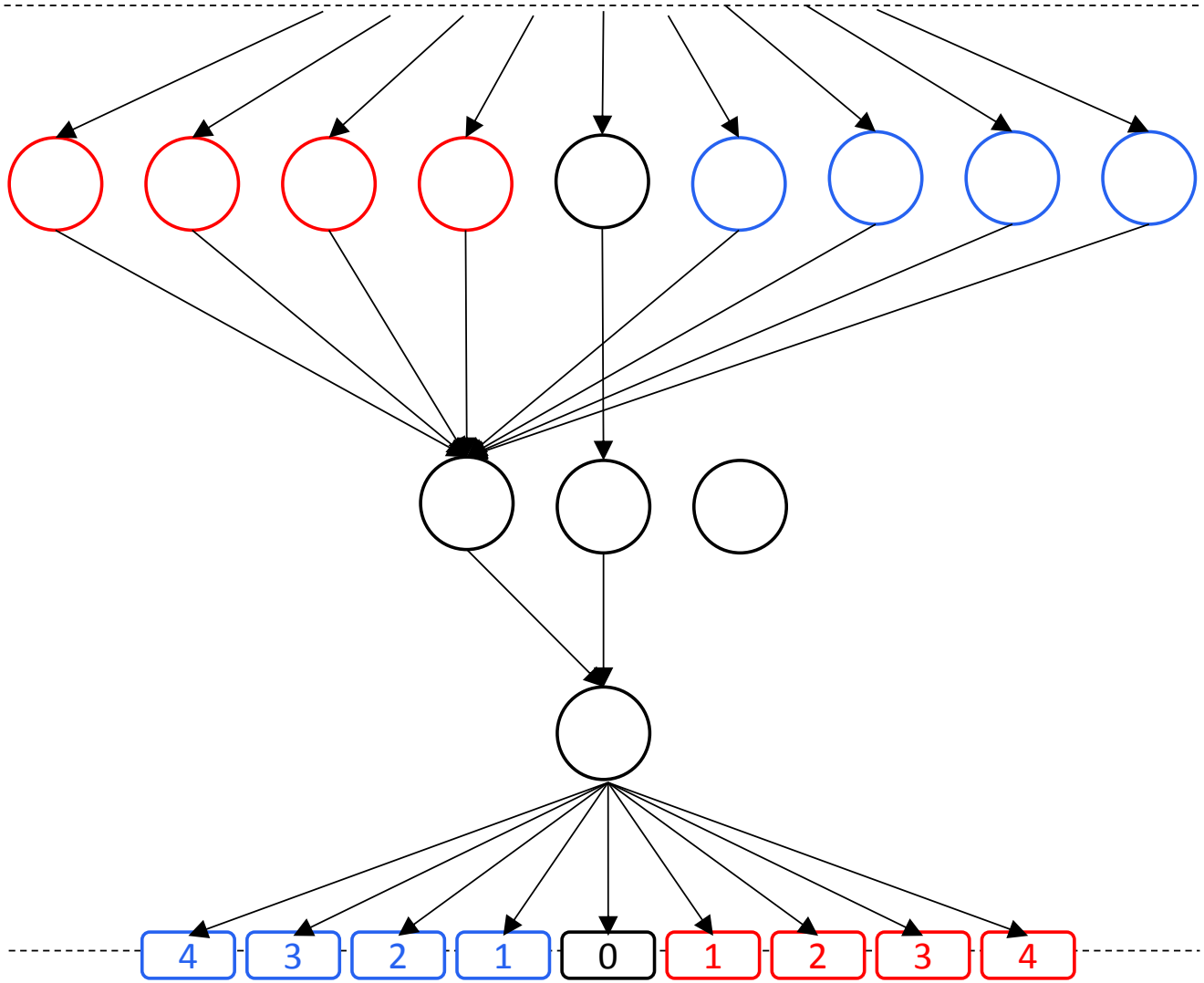

Figure: The XOR strategy translated in terms of network topology

XOR strategy

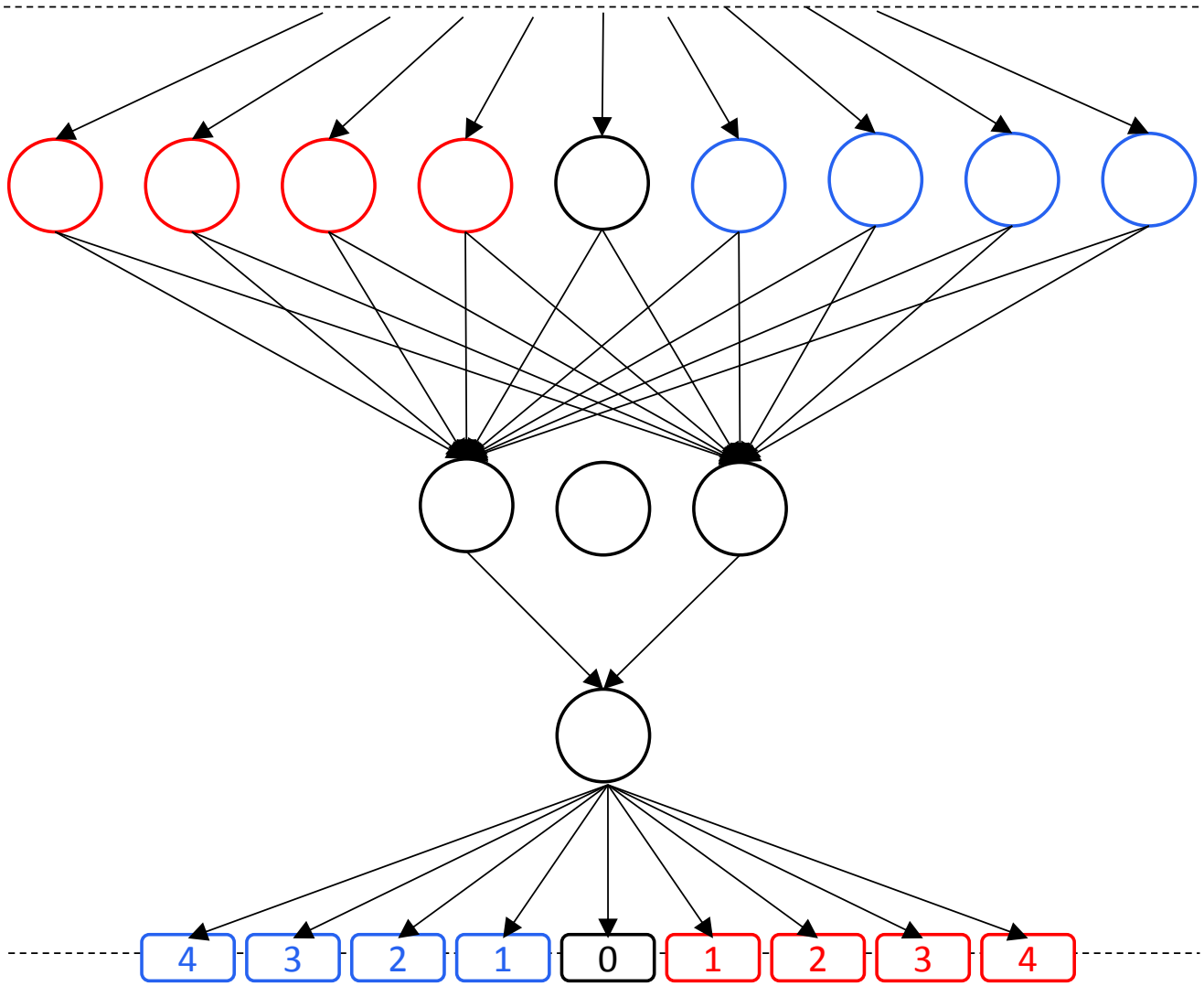

Figure: Another XOR strategy translated in terms of network topology

Genetic Algorithm: studying the market through time

In this section we will specify the genetic algorithm which we have used to study our problem. Throughout this subsection we will refer to Micro and Macro increments. We will define two types of iterations:

- the first type being **Micro** corresponding to an infinitesimal increment in our environment namely, an increment in which a strategy S analyses and in turn changes the order book by placing a order itself.
- the second type being **Macro** corresponding to a generational increment in our environment namely, *a certain equal number* of Micro increment per strategy leading to a calculation of P&L and a survival process[1] based on this P&L.

[1] explained next

Genetic Algorithm: studying the market through time

We will label N_k the number of total alive strategies, N_k^e the number of tr**e**nd following like strategies, N_k^m the number of **m**ulti-linear regretion like strategies, N_k^r the number of xo**r** like strategies and N_k^o the number of **o***ther unclassified* strategies. The relationship between these entities can be summarized by equation (6).

$$N_k = N_k^e + N_k^m + N_k^r + N_k^o \tag{6}$$

A strategy will consist of a topology $\mathcal{T}$, a rolling P&L $\mathcal{P}$ and a common orderbook $\mathcal{O}$ as shown by equation (7).

$$\mathcal{S} \triangleq \{\mathcal{P}, \mathcal{T}, \mathcal{O}\} \tag{7}$$

Genetic Algorithm: studying the market through time

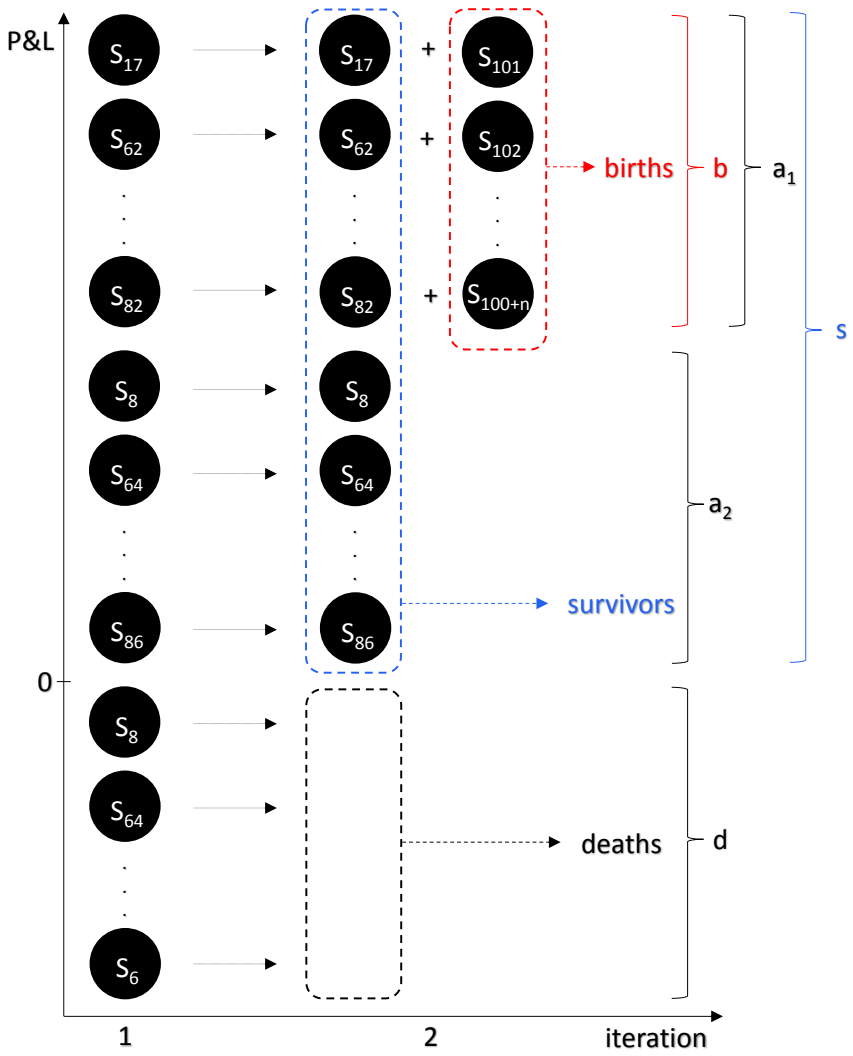

Figure: Illustration for the Death and Birth processes in our GA

Inheritance with Mutations

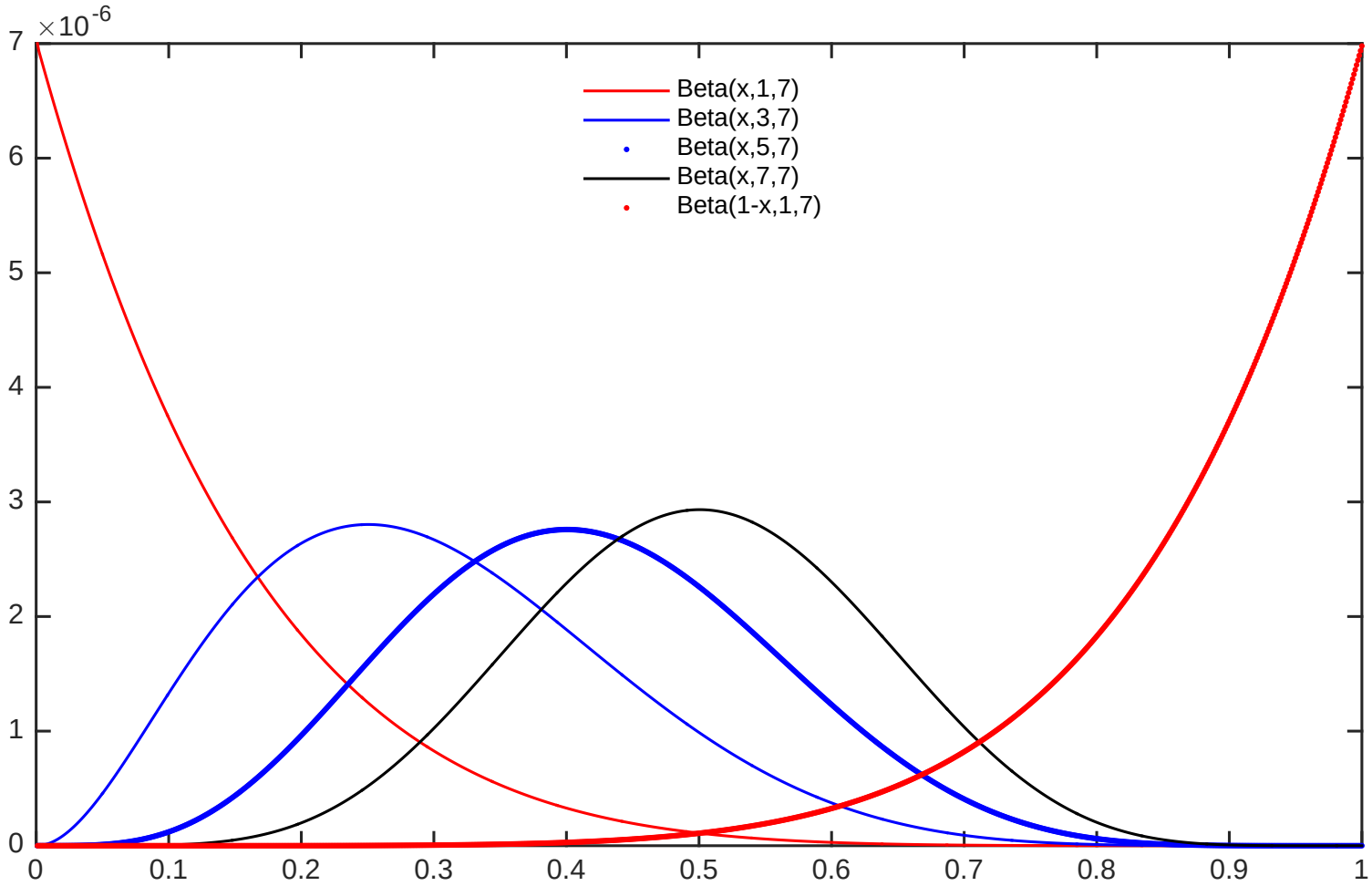

Figure: PDF of the beta distribution for different combinations of (α, β)

Inheritance with Mutations (weight resampling)

$$\begin{aligned}\mathcal{D}(\tilde{x}) &= 1_{\tilde{x}\leq -\frac{1}{5}}\mathcal{B}eta\Big(\frac{\tilde{x}+1}{2};\alpha(\tilde{x}),\beta\Big)\\ &\quad +1_{\tilde{x}>\frac{1}{5}}\mathcal{B}eta\Big(1-\frac{\tilde{x}+1}{2};\alpha(\tilde{x}),\beta\Big)\\ &\quad +1_{|\tilde{x}|\leq\frac{1}{5}}f(\tilde{x})\end{aligned} \tag{8}$$

$$\alpha(\tilde{x}) = \begin{cases}1, & \text{if } 1>|\tilde{x}|\geq\frac{3}{4}\\ 3, & \text{if } \frac{3}{4}>|\tilde{x}|\geq\frac{1}{2}\\ 5, & \text{if } \frac{1}{2}>|\tilde{x}|\geq\frac{1}{5}\end{cases} \tag{9}$$

$$F(k) = \begin{cases}\frac{1}{10}, & \text{if } k\leq-\frac{1}{5}\\ \frac{8}{10}, & \text{if } |k|<\frac{1}{5}\\ 1, & \text{if } k\geq\frac{1}{5}\end{cases} \tag{10}$$

with $\tilde{x}\in]-1,1[$, $\beta=7$ and the function $\alpha(\tilde{x})$ is the **interval of condition**.

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Observations

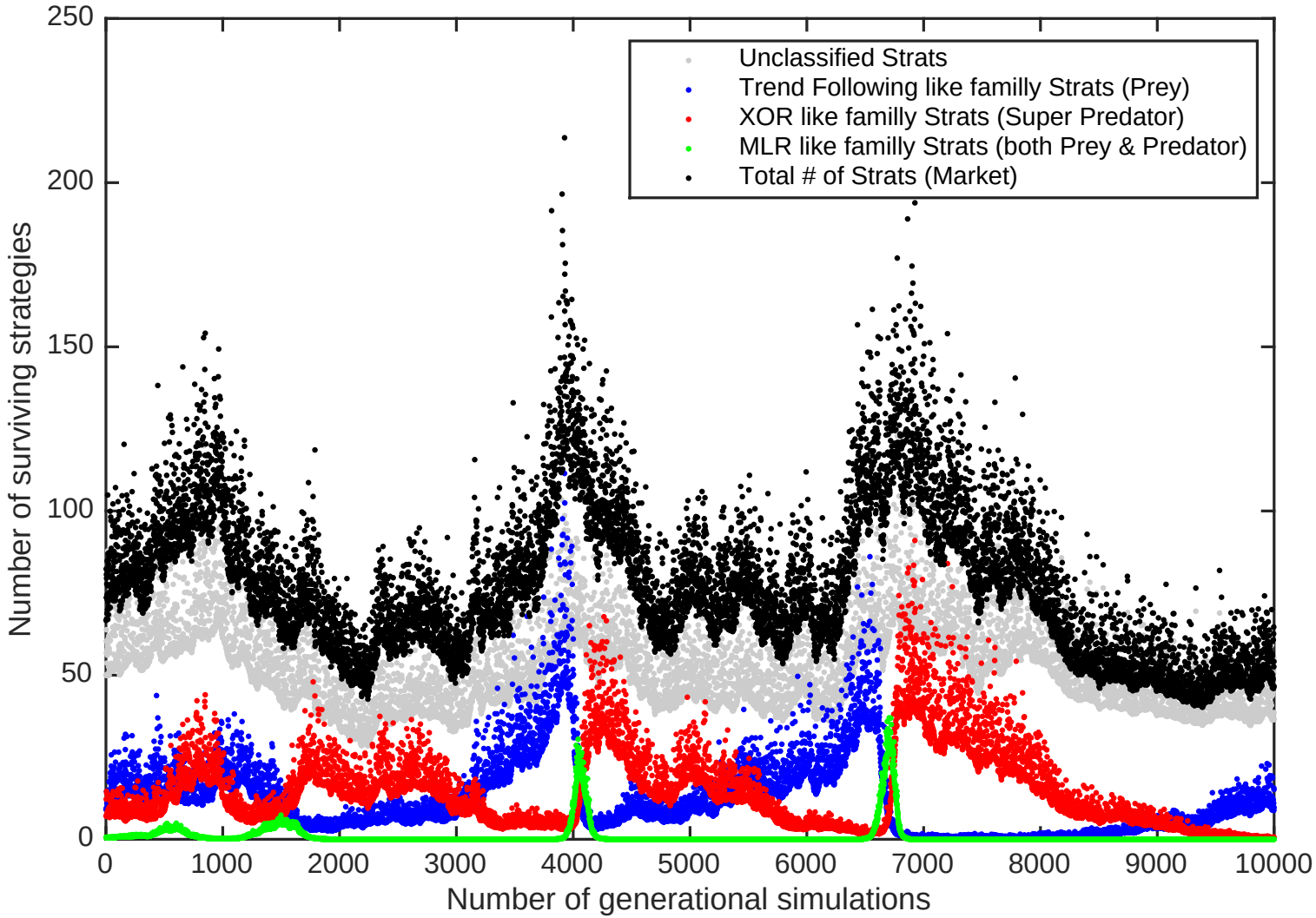

Figure: A HFTE Simulation

Observation & Interpretation

Observation:

- zone A: from around simulation 3500 to 4500
- zone B: from around simulation 6000 to 7500

We notice the following similarities between zone A and B:

- The market was bullish in the first 500 Macro steps of the zones then became bearish in the next 500 Macro steps of the zones,
- The TF type strategies, first increases in frequencies then diminishes suddenly in the middle of the zones,
- The MLR type strategies increases in a short burst right in the middle of the zone and immediately decreases,
- The XOR strategies frequency increases suddenly in the middles of the zones and decreases slowly

Interpretation: The TF, MLR and XOR strategies behave like the Lotka Volterra 3 species predator prey model.

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Application and Future Research

Assuming that the P&L lost by a strategy is linearly gained by another which leads us to assume that $a = a_1 = \ldots = a_{N_t^a} = 1$ and $b = b_1 = \ldots = b_{N_t^a} = 1$. Finally the regulators may assume that the maximum number of strategies M can be fixed to the number of market participants.

$$\begin{cases} \frac{dx}{dt} & = x - xy_1 \\ \frac{dy_1}{dt} & = xy_1 - y_1y_2 \\ \frac{dy_2}{dt} & = y_1y_2 - y_2y_3 \\ \vdots & = \quad \vdots \quad\quad \vdots \\ \frac{dy_{N_t^a-1}}{dt} & = y_{N_t^a-2}y_{N_t^a-1} - y_{N_t^a-1}z \\ \frac{dy_{N_t^a}}{dt} & = y_{N_t^a-1}y_{N_t^a} - y_{N_t^a}z \\ \frac{dz}{dt} & = -z + y_{N_t^a}z \end{cases} \tag{11}$$

HFTE Summary & Outstanding issues

HFTE Size	**Main Players**	**Main Results**	**Main Problems**
3 Strats	TF, MLR & XOR	Parallel to LV 3-Species Predator Prey model	network topology to strats
4 Strats	Above + random	Stability of Market, use dual biology problem	same as above
n Strats	Complex set & of above	Complex "Food Web" + foresight strat (farming)	Diversity in strats lead to instability?

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Definition: approved persons

The legal duties of an approved person are given in Section 2 of the Financial Services and Markets Act (FSMA 2000). This also spells out the purpose of regulation by specifying the FSAs four statutory objectives:

- Maintaining confidence in the financial system.
- Promoting public understanding.
- Protecting consumers.
- Reduction of financial crime.

Approved persons follow the following **principles** (similar objectives are set out by the SEC):

- Integrity.
- Skill, care, and diligence.
- Proper standard of market conduct.
- Dealing with the regulator in an open way.
- Proper organization of business.
- Skill, care, and diligence in management.
- Compliance with regulatory requirements.

Regulatory problems at the low frequency

What is currently being done: driven by **media coverage**, regulators (SEC and the FCA) have been improving **fraud detection** (whistle-blower program) and **overt risk-taking** (bonus associated to multiple years of experience) in the financial industry.

- Unfortunately, results seem to indicate that the guidelines are not always respected. Whether **belief bias** (if someone has already accepted a conclusion), or whether the rules are taken lightly, the results are that fraud cases are still being report regularly.
- The **problem** is that the rules do not stress enough the moral and **biological ramifications** (apophenia + reinforcement for seeing money come in) work against the applications of the rules.
- **What could be done to improve the industry**: there is still more that could be done, for instance, preventing institutions from using **correlation** when it is inappropriate. Also, many traders and structurers should get the opportunity to realize and be educated with respect to **apophenia**.

Regulatory problems at the high frequency

We showed that the stability of the financial market comes to studying some form of the Lotka-Volterra dynamics, however the stability methodology was subject to **knowing the frequency of each strategy** type in our ecosystem, something unavailable currently for few reasons:

- Market participants are unwilling to **divulge** their systematic **strategies**.
- In the unrealistic event in which market participants were to divulge their strategies, them **changing their mind** because of unforeseen events would not be visible to the regulators.
- The regulators do not have the **computational savvy** to get and process the relevant data.
- **Moral questions** would be raised as the regulators would be able to predict which market participants could lose money and which ones would make money before it actually happens.